

CHAPTER 23

HIGH LEVEL RADIOACTIVE WASTE MANAGEMENT IN SWITZERLAND: BACKGROUND AND STATUS 1995

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23.1 BACKGROUND

Switzerland is a small country, with limited natural resources (other than hydro power) and must import about 80 % of its primary energy needs (predominantly petroleum products). Electricity covers about 20 % of energy demand; about 40 % of the electrical energy is supplied from nuclear plants, with almost all the rest being generated by hydropower.

Nuclear power production is the main source of Swiss radioactive wastes, although wastes arise also in medicine, industry and research. Switzerland currently has 5 nuclear power plants (pressurized water reactors and boiling water reactors) with a total capacity of 3 GW(e). The spent fuel, containing most of the waste radionuclides produced by fission, may be prepared for direct disposal or reprocessed to recover useable uranium and plutonium, with the resulting wastes being immobilized in glass blocks. To date, Swiss disposal planning has focused on waste returned from foreign reprocessing plants but, currently, the preferred strategy of the utilities is to keep open both options (reprocessing or direct disposal). The prime reason for originally choosing the reprocessing route was to optimize use of resources; the current arguments against reprocessing are primarily economic.

Nuclear power and its future role in the nation's energy mix is a controversial issue. The initial widespread acceptance has been replaced to a significant extent by uncertainty or even opposition; this led in 1990 to the adoption by popular referendum of legislation placing a 10 year moratorium on expansion of nuclear power. The waste disposal issue, as will be detailed in the following section, plays a prominent part in the debate on nuclear energy. There is a strong incentive for those responsible for waste management to ensure that continuing

progress is made towards development and implementation of an integrated waste management strategy.

23.2 LEGAL, REGULATORY AND ADMINISTRATIVE ISSUES

The Atomic Law of 1959 clearly placed the responsibility for nuclear waste disposal with the producer of the waste. The Ruling of 1978 further stipulates that *"The general license for nuclear reactors will be granted only when the permanent, safe management and final disposal of radioactive waste is guaranteed."* This Ruling was extended by the Government to existing reactor operating licenses and this led to preparation of a special Project Gewähr (PG85) which, as described below, was submitted to the Government for review in 1985¹.

The safety conditions which the final repositories must satisfy are defined in the Guideline R-21 (1980, revised 1993) of the Nuclear Regulatory Authorities. Three protection objectives are defined:

- The repositories must ensure the safety of human beings and the environment from any harmful effects of ionizing radiation. Accordingly, the central point is Objective 1, which states: "Radionuclides which can be released into the biosphere from a sealed repository as a consequence of realistically assumable processes and events may not at any time lead to individual doses which exceed 10 mrem (0.1 mSv) per year." This objective is ambitious not only because of the absence of any time limit for demonstration of compliance but also because of the comparatively low levels of radiation doses permitted. For comparison, the natural radiation exposure of the Swiss population results in an average radiation dose of about 140 mrem per year, with a range of approximately 100 to 300 mrem per year.

- Objective 2 provides a quantitative risk level for judging the consequences of low-probability scenarios: "The individual radiological risk of fatality from a sealed repository subsequent upon unlikely processes and events not taken into consideration in Protection Objective 1 shall, at no time, exceed one in a million per year". The direct radiological risk of fatality from a scenario is thus multiplied by the estimated probability of the scenario occurring and this product should not exceed one in a million per year when summed over all such scenarios. For comparison, the dose limit of 0.1 mSv per year corresponds to a nominal risk of fatality of 5 in a million per year.
- Besides the safety aspects, the Guideline R-21 reflects the understanding that the responsibility for disposing of radioactive waste lies with today's beneficiaries of nuclear power and should not be passed on to future generations. This is expressed in Objective 3: "A repository must be designed in such a way that it can at any time be sealed within a few years. After a repository has been sealed, it must be possible to dispense with safety and surveillance measures." Once the repository has been sealed, it must thus be possible to "forget" the radioactive waste in the sense that it should not be necessary for future generations to concern themselves with it. There is thus no requirement for monitoring or retrievability of the waste.

In addition to the requirements formulated in these three protection objectives, non-nuclear regulations must also be taken into consideration; these include international law, district planning, environmental protection; and nature conservation.

As noted above, the producers of nuclear waste are responsible for waste management (for all waste categories). Hence the electricity supply utilities involved in nuclear power generation and the Swiss Confederation (which is directly responsible for the waste from medicine, industry and research) joined together in 1972 to form the "National Cooperative for the Disposal of Radioactive Waste" (Nagra). Nagra is responsible for the disposal and, if required, pre-emplacement conditioning of wastes. The responsibility for spent fuel reprocessing and transport, for the waste conditioning at power plants and for interim storage remains directly with the utilities. In 1994, a separate organization was founded to actually construct and operate a L/ILW repository at a site selected by Nagra, the Genossenschaft für die Nukleare Entsorgung

Wellenberg (GNW).

23.3 CHARACTERISTICS AND EVOLUTION OF THE SWISS NUCLEAR WASTE DISPOSAL PROGRAMME

Since the founding of Nagra in 1972, work has been carried out on the development of disposal concepts and identification of potential sites for such facilities. Working on the principle of the multi-barrier concept, the requirements for packaging, engineered structures and geological isolation were derived for different types of waste. Two separate geological repositories are planned²; one for low-level radioactive wastes and shorter-lived intermediate-level wastes (L/ILW) and another for high-level wastes (HLW) and intermediate-level wastes containing higher concentrations of long-lived alpha-emitters ("TRU").

Highest priority at present is allocated to the L/ILW repository which is intended to be implemented in horizontally accessed rock caverns with some hundreds of metres of overburden. An extensive site-selection procedure resulted in 1993 in the nomination of Wellenberg in Central Switzerland as the preferred repository location. More detailed site-characterization work, to form the basis of the application for construction and operation permits, is now ongoing. The principal for the development of Wellenberg as a repository site has been accepted in public Referenda at the community level. It is also supported by the federal authorities. At the cantonal level, however, there has been opposition, leading in 1995 to a popular vote which produced a narrow majority against the currently proposed project. Nevertheless, current planning assumes that, following appropriate amendments to the project, the L/ILW repository should be operational early next century.

For the present limited nuclear programme in Switzerland, operation of all plants for a 40 year lifetime will result in around 3000 t of spent fuel. If all of this were reprocessed abroad, the resulting volume of vitrified waste returned would only be around 500 m³, although several thousand cubic metres of additional L/ILW could also be returned (depending on the contract with the reprocessor). It is planned to store HLW for at least 40 years in order to reduce the thermal loading of the repository, so that ample time is available for project development. A centralized facility for dry cask storage of spent fuel and of vitrified HLW and for other reprocessing wastes will be constructed before the turn of the century by the ZWILAG organization, a daughter company of the utilities.

Implementation of a HLW repository will not take place in Switzerland before the year 2020, and there are sound economic arguments for delaying this date even further. Nevertheless, there is strong pressure from the public and the government - and a strong will on the part of the waste producers - to move the project ahead as quickly as possible, at least up to the level of demonstrating the feasibility of construction of a safe repository at a potential site.

Site selection is very much constrained by the small size of Switzerland and by its relatively active tectonic setting. The current geological consensus is that the orogeny which built the Swiss Alps is still continuing and there is still net uplift in this area of ~1-2 mm/year (which is equivalent to 1-2 km in the million year timescale which is considered for HLW safety analysis!). Excluding alpine areas and other complex geological structures associated with the Jura mountains and the Rhine Graben leaves only a limited area in Northern Switzerland which would be potentially suitable. Within this area, two host rock options are considered - either the crystalline basement or one of the overlying, low permeability sediment layers.

The current conceptual repository design was developed taking into account the potential host rocks, the very low volumes of HLW expected and the government requirement for an early, convincing demonstration of safety of waste disposal as a condition of extending reactor operating licenses. These factors together led to designs which are certainly robust (or even overdesigned) and are not optimized in an economic sense. Accordingly, although estimates of absolute costs for the small size repository required are comparable to those from other countries, the costs per unit waste volume (or per kWh of nuclear electricity) are relatively high. Optimization of designs would, therefore, clearly be an important objective before moving to an implementation phase. The concept, illustrated in Figure 23.1 for the crystalline host rock option³, has the following features:

1. extremely deep disposal (about 1 km below surface) in a carefully-constructed facility;
2. in-tunnel emplacement of HLW waste packages in a geologic medium whose principal roles are to limit water flows and to ensure favorable groundwater chemistry;
3. very massive engineered barriers; in addition to the vitrified waste in its steel fabrication canister, a 25 cm thick steel overpack is envisaged which is surrounded by more than one metre of highly compact-

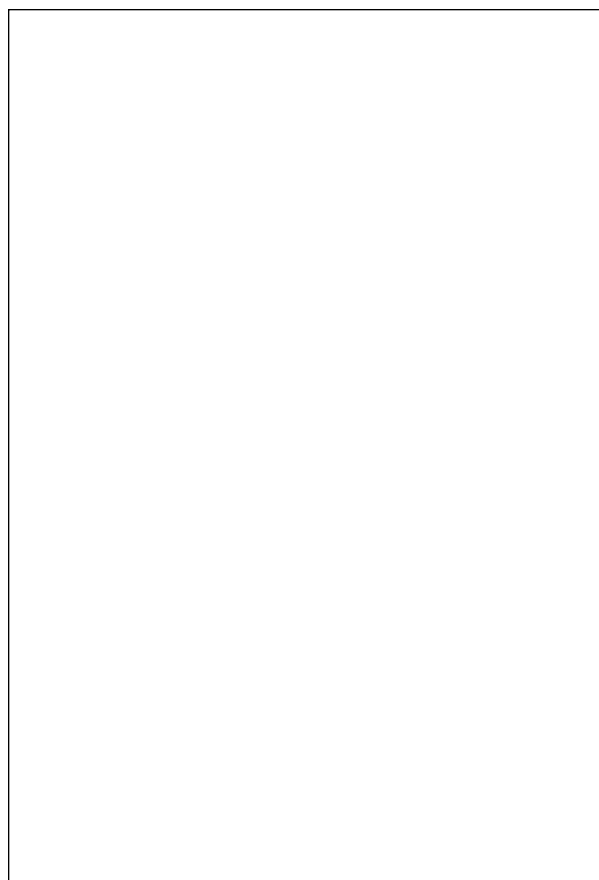


Figure 23.1. Sketch of possible repository layout. The case of 3 HLW emplacement panels on a single level and TRU silos in separate blocks of low-permeability basement between major (layout-determining) water-conducting faults.

- ed bentonite clay (Fig. 23.2); and
4. co-disposal of TRU in silos or in caverns in a separate part of the repository.

Analysis of this concept in the Project Gewähr 1985 study (mentioned above), showed that, for all realistic scenarios analyzed, the performance guideline was met with large margins of safety. In their review of this project, the government concluded that this concept would provide sufficient safety in a crystalline basement having the properties postulated by Nagra. However, only limited data from isolated boreholes were available in 1985, and the Government authorities requested more evidence that suitable rock formations of an appropriate extent could be identified in Switzerland. The government review also strongly recommended that the option

Figure 23.2. Waste emplacement geometry (dimensions in metres).

of disposal in sedimentary formations be considered in more depth. Despite these caveats, the waste disposal issue was no longer tied directly to operation of existing power plants, although it is understood that more evidence of siting feasibility would be required before any applications for new reactor licenses could be sought.

Since 1985, the regional investigation of the crystalline basement has been completed and documented⁴. The geological studies have clearly shown that the extent of the accessible crystalline basement is much less than originally thought due to the presence of a previously unknown, extensive Permocarboniferous trough which cuts the region. Only two restricted areas remain for selection of a possible site, each covering about 50 km². Nevertheless, it does seem feasible to find a suitable repository for the required low volume of waste and a strategy for site characterization has been developed. In parallel, investigations of the sedimentary options have proceeded from a desk study to select potential host formations through to identification of specific potential siting areas. The two sedimentary host rocks investigated in detail were Opalinus Clay, which exists in a laterally extensive but rather thin layer in Northern Switzerland, and Lower Freshwater Molasse, where the

formations are large but somewhat heterogeneous⁵. For Opalinus Clay, which was identified as the higher priority option for Nagra, a total potential siting area of some 100 km² has been identified. Programmes of site-specific studies are now running in parallel in the crystalline basement and the Opalinus Clay.

The next major milestone in the HLW programme will be the demonstration of repository siting feasibility (Project Entsorgungsnachweis) scheduled for 2000. This may include one or both of the potential siting areas studied.

23.4 ONGOING GEOLOGICAL STUDIES ASSOCIATED WITH THE HLW PROGRAMME

Geological characterization prior to repository construction is planned to progress in three phases. Phase I is a regional study of potential host rocks from the surface, involving seismic studies, investigation from deep boreholes, etc. This phase is followed by more detailed investigations of a potential siting area from the surface (Phase II), and then Phase III underground studies involving construction of an access shaft to the potential repository depth and an underground laboratory.

Phase I has been completed and documented for both the crystalline basement and Opalinus Clay^{4,5}. For the former, the most relevant open question to be addressed in Phase II is the distribution of major shear zones within the crystalline basement. A detailed performance assessment (see below) has demonstrated that blocks of low permeability crystalline basement found in the area north of the North-Swiss Permocarboniferous Trough (Fig. 23.3) would be a very suitable host rock. Statistical analysis of major faults identified during Phase I (by geophysics, borehole mapping, mapping surface exposures in the neighboring Black Forest etc.), indicates that the probability of finding sufficiently large blocks for repository construction in this area is high. This statistical model will be tested by drilling a “star” of four inclined boreholes at a site to be chosen in Northern Switzerland (cf. Fig. 23.4). Location of “layout-determining” faults will be on the basis of core-logging, complemented by cross-hole hydro-testing and cross-hole seismic tomography. In addition, a surface campaign of seismics will be carried out. For the crystalline basement, this technique is somewhat limited as it identifies only faults which cause significant displacement in overlying sedimentary formations; no clear determination of structure within the basement is possible using this method.

In contrast, however, the Opalinus Clay formation is a clearly defined seismic reflector which can be well mapped by the planned 3D seismic survey. It is relatively homogeneous in composition and, in the area of interest, shows little evidence of tectonic disturbances. The planned borehole at a site near the village of Benken is aimed primarily to calibrate the seismic studies. Somewhat more problematic in the Opalinus Clay case, however, are the mechanical properties of this rock. Studies to date indicate that emplacement tunnels for HLW and caverns for TRU could be constructed at depths of up to ~800 m, but the extent of tunnel linings required needs to be established based on site-specific, rock mechanics data.

The demonstration of siting feasibility also requires geological input which cannot be obtained from these two sites in any easy way. Some generic data for crystalline and sedimentary rocks can be obtained from other national programmes, but underground laboratories in Switzerland provide a key testing ground for methodology development and use of destructive characterization methods.

Nagra's main underground test site is situated at Grimsel Pass in the Swiss Alps⁶. This facility is situated

in granite/granodiorite below ~500 m of overburden. Although tectonically unsuitable for a HLW repository, this site has played an important rôle in the development of the technology required for site characterization. In the present phase of work (Phase IV, 1994-1996), HLW-relevant studies include testing of the limitations of current methods of seismic tomography, examination of the properties of the excavation-disturbed zone around tunnels through crystalline rock, validation of models of radionuclide migration through fractures, and demonstration of the methodology for emplacement of HLW packages. A final Phase V of work at Grimsel, lasting until 2002, is currently being planned.

A further underground test site has been initiated within the scope of an international project, utilizing a road tunnel through the Opalinus Clay at Mt. Terri in the Jura mountains. Studies at this site include examination of water flow paths through this formation and also characterization of the excavation-disturbed zone in this formation.

23.5 MAKING THE SAFETY CASE FOR HLW

Over the last decade or so, several countries have published comprehensive assessments of the safety of various disposal options for vitrified HLW and spent fuel. It has been found that these concepts differ quite significantly from each other and place the emphasis for a demonstration of safety on different parts of the multi-barrier system. At one extreme, the German concept of HLW disposal in a salt dome places emphasis on the role of the host rock in isolating the waste from advective water flow for very long time periods. Another concept with strong emphasis on geological barriers is illustrated by the Belgian concept of disposal in plastic clay. Canadian disposal in granite with very low hydraulic conductivity also emphasizes the geologic barrier, although long-lived container designs are also considered. At the other extreme, the Swedish concept for spent fuel encapsulation in thick copper canisters achieves long-term isolation by depending on the inertness of copper (which gives an expected canister life in the order of a million years and places very modest requirements on the geologic medium). The Swedish concept has also been adapted to Finnish conditions.

The Swiss concept places less emphasis on the retention capabilities of the geosphere or on the performance of individual engineered barriers; rather, it focuses on the behavior of the near field (all engineered barriers in their geological setting) as a whole^{7,8}. Following waste emplacement, this near-field environment evolves in a

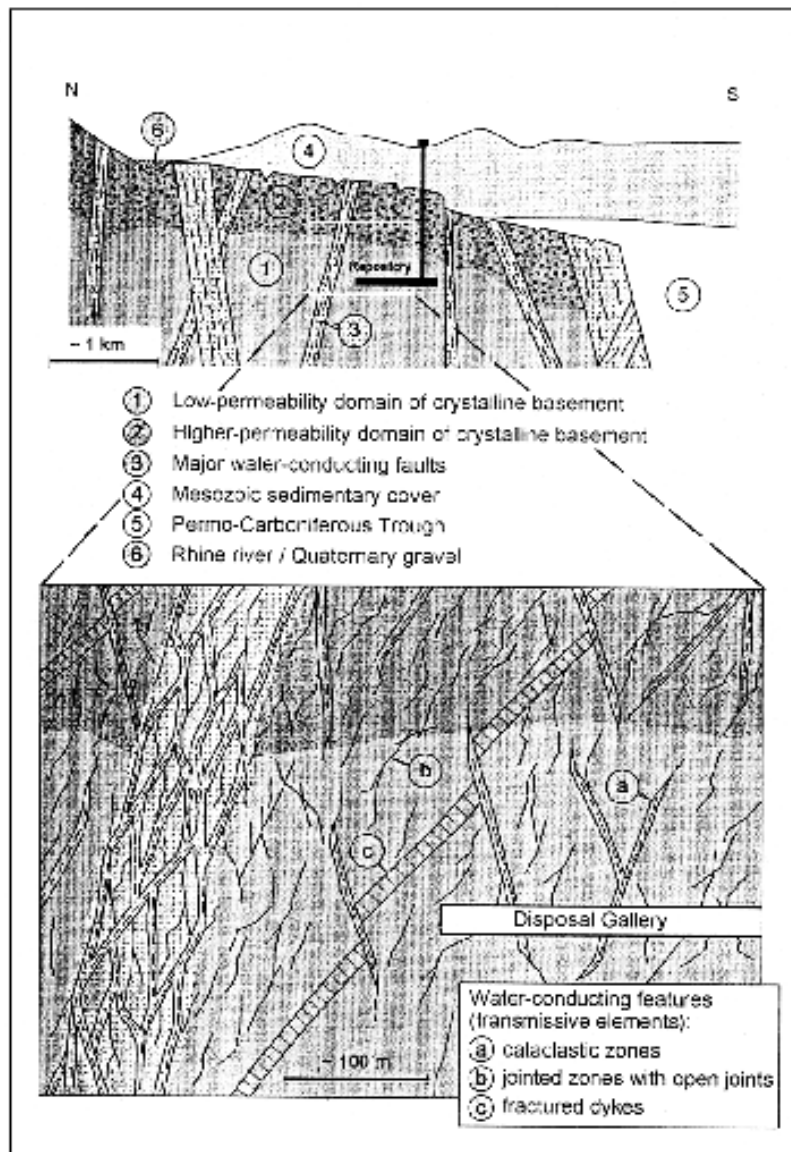


Figure 23.3. Diagrammatic representation of the conceptual model of the crystalline basement.

well defined manner.

After emplacement, water will resaturate the surrounding rock and then invade the bentonite which will swell to seal any gaps. Temperatures in the bentonite will increase due to heat from the canister, but storage of waste prior to emplacement ensures that the maximum temperature in the backfill does not exceed $\sim 160^{\circ}\text{C}$. Calculations indicate that complete resaturation may take in the order of hundreds of years. The steel canister corrodes anaerobically at a very low rate (~ 50 m/year). Only after ~ 1000 years will mechanical failure occur due to pressure from the expanding bentonite. The water

chemistry in the compacted bentonite will be determined by interactions of inflowing granitic groundwater with mineral surfaces in this microporous material. The bulk of the bentonite itself will not undergo any significant mineralogical alteration over relevant timescales (~ 1 million years).

After canister failure, corrosion of the glass will occur in an environment with effectively stagnant porewater. Corrosion of the glass is expected to gradually release the contained radionuclides over a period of the order of 10^5 years. The release of many radionuclides may, however, be further constrained by their very low solubili-

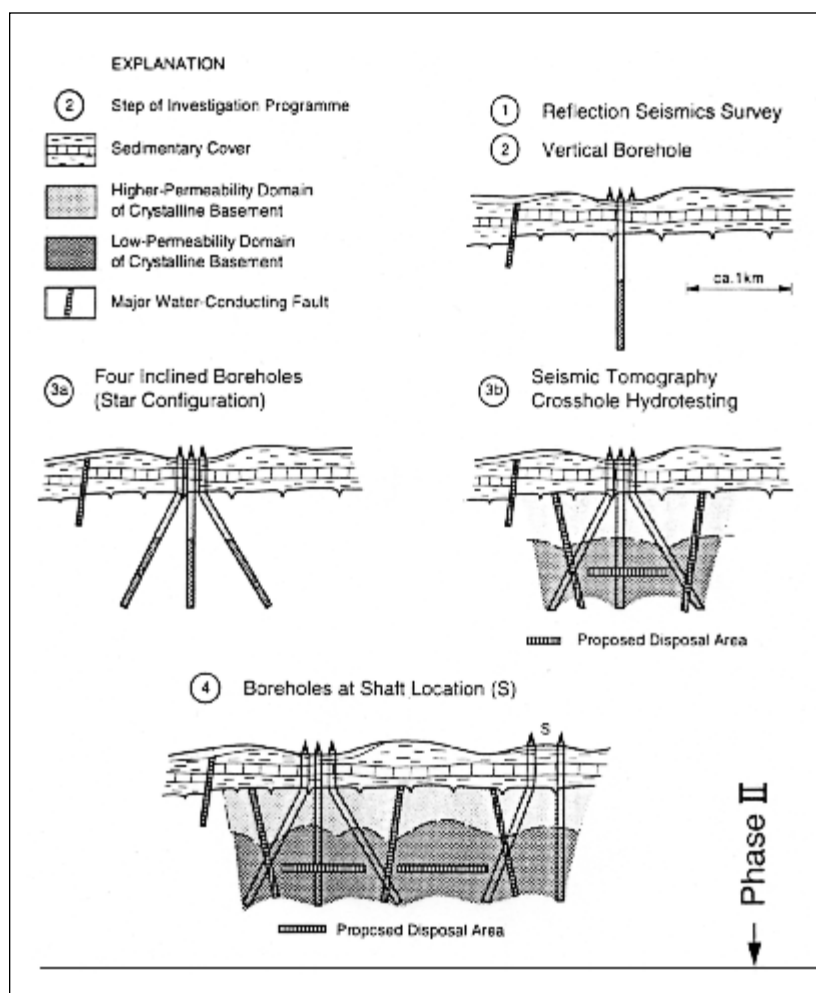


Figure 23.4. Illustration of the investigation concept for the crystalline basement.

ties. Even after radionuclides are released from the glass matrix, output to the geosphere is greatly limited by the transport resistance of the bentonite backfill. Due to its extremely low hydraulic conductivity, solute transport through the saturated bentonite will occur predominantly by diffusion. Sorption processes result in very low diffusivities for many radionuclides, so that their transport time through the backfill exceeds their half-lives, and thus, output is negligible. This analysis of the repository near field is believed to be robust⁷, in that it does not take credit for all possible processes which would decrease release rates, and is relatively insensitive to the variation of uncertain parameters within reasonable ranges.

Although sufficient safety can be demonstrated with only minimal requirements on the geology, the geological barrier can also be extremely powerful, reducing the

already low concentrations of radionuclides yet further. Under the expected geological conditions in Northern Switzerland, the geological barrier would ensure that, in effect, no releases to the human environment would occur for all timescales which are meaningful (up to one million years). The calculation of retardation of radionuclides in the geosphere is, however, more sensitive to parameter values which are difficult to determine in the field and hence a safety case based strongly on the barrier effect of a fractured geologic medium is less robust.

The demonstration of long-term safety for a HLW repository must be based upon predictive modeling, and it is important to realize the capabilities and the limitations of such models. The mathematical models used in performance assessment are supported by a range of laboratory and field experimental studies, but the extrapolation of such work to very long timescales must

also be justified. Enhanced confidence in our understanding of long-term performance of the near-field, in particular, may be illustrated by using natural analogues.

A natural analogue is a process that has occurred in the past and is similar to those that are predicted to occur in the future evolution of a repository. The proposed corrosion rates of the waste matrix and canister in the expected chemically reducing environment can be supported by observation of the preservation of archaeological glass and steel artifacts over millennia. Mineralogical stability of bentonite can be shown on an even longer timescale by observations of natural bentonites that have remained unaltered for millions of years in conditions comparable to those expected in the repository. Even the ability of clay to isolate radioactive substances can be illustrated by natural ore bodies in appropriate geologic settings.

A safety case made on the robustness of a system of engineered barriers appears to be appropriate to the Swiss geological environment, and it is interesting to note that a very similar concept has been adopted by Japan (a country with even more complex and tectonically active geology than Switzerland) in their H-3 performance assessment.

23.6 THE SWISS PROGRAMME IN AN INTERNATIONAL CONTEXT

The Swiss waste management programme, although relatively small in terms of budget and manpower, is very wide in scope, with one site currently being characterized in detail for a L/ILW repository and two types of host rocks under investigation for disposal of vitrified HLW and long-lived ILW. This programme is only feasible if priorities are set and adhered to, and if maximum advantage is taken of work performed elsewhere. Therefore, extensive use is made of international collaboration agreements in order to spread the work load. Individual information exchange agreements with other programmes have allowed effort to focus in specific areas. For example, Switzerland could deliberately concentrate on studies of steel canisters for HLW because Sweden has concentrated on copper, and a bilateral Nagra/SKB agreement provided for exchange of results. Such agreements also allowed direct cooperation/co-funding of larger studies, such as the Japan/Sweden/Switzerland (JSS) study of the leaching of vitrified HLW. Cooperation with the US DOE has allowed results from the Swiss underground test site to be made available to modeling groups in the US who, in turn,

make their interpretations available to Nagra.

Apart from active participation in the IAEA and the NEA, Nagra has formal agreements with the European Economic Community (EEC), United States (DOE, NRC), Sweden (SKB), Finland (Posiva), France (CEA and ANDRA), Belgium (ONDRAF, CEN/SCK), Germany (GSF/BRG), Japan (PNC), Spain (ENRESA), Taiwan (AEC) and the United Kingdom (NIREX). Informal collaborations extend the list further.

23.7 CONCLUSION

Despite its small size and limited nuclear power capacity, Switzerland has succeeded in establishing an internationally recognized programme for management of radioactive wastes. The restricted size makes lines of communication shorter and coordination of effort simpler. The relatively strong economy makes the financing of projects, without the benefits of scale, a feasible proposition, although the economic sense of establishing various small-scale projects through the world can be questioned. Sound technical projects can be developed and implemented with limited human resources, provided that care is taken to make polyvalent use of expertise and to profit from mutually beneficial collaboration with other national programs. Even front-line science and advanced engineering skills are, however, of little use if public opposition prevents their application. Hence, it is important that a waste management organization like Nagra devotes strong efforts to communication with the public at all levels.

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